AI-Driven Energy Efficiency versus AI-Induced Energy Demand: A Dynamic Computable General Equilibrium (CGE) Analysis of Vietnam's Twin Transition

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Abstract. Artificial Intelligence (AI) acts as a double-edged sword in the energy transition: its deployment in heavy industry generates productivity dividends that reduce energy intensity (the "Green AI" effect), while the data centers and hardware required to run it surge electricity demand and strain emerging-economy power grids (the "Brown AI" effect). This paper quantifies both effects and their interaction for Vietnam using a 23-sector recursive dynamic Computable General Equilibrium (CGE) model calibrated to the 2019 Input-Output Table and simulated through 2035. Three scenarios are evaluated: Green AI (S2), modelled as a Total Factor Productivity (TFP) shock to heavy manufacturing and electricity; Brown AI (S3), modelled as an exogenous investment surge in Information Technology (IT) hardware and services; and a combined Twin Transition (S4). Green AI delivers a compounding GDP dividend of +0.98% by 2030 and +1.79% by 2035, with consumption rising +1.17% and +2.03%. Brown AI is macro-neutral in GDP terms but imposes a consumption cost of −0.42% by 2030 as infrastructure investment crowds out household expenditure. The Twin Transition is approximately macro-additive (GDP +1.06% by 2030 and +1.95% by 2035), with consumption recovering to +1.70% above baseline by 2035. The dominant structural trade-off is distributional: real exchange rate appreciation generated by Green AI's export surge displaces Textiles (−5.5%) and Leather and Footwear (−16.1%), even as Heavy Manufacturing (+12.9%) and IT Hardware (+10.9%) expand substantially. Under S3 alone the Electricity sector expands only +0.10% by 2030 against a 14.87% per year IT investment surge, indicating a binding generation capacity that the Green AI productivity shock relaxes in S4. The Twin Transition is macro-feasible, but its adjustment costs fall unevenly on the manufacturing workforce.

Keywords: Artificial Intelligence; Computable General Equilibrium; Energy Transition; Vietnam; Structural Transformation; Distributional Effects

1 Introduction

Artificial Intelligence (AI) is simultaneously the most promising instrument for industrial decarbonization and one of the fastest-growing sources of electricity demand. On the one hand, AI-driven process optimization, predictive maintenance, and smart grid management are reshaping the energy intensity of heavy manufacturing: facilities within the World Economic Forum (WEF) Global Lighthouse Network have demonstrated average energy consumption reductions of 22% through AI-enabled production monitoring, with some achieving up to 59% [1, 2]. On the other hand, the physical infrastructure required for AI consumes extraordinary amounts of electricity. A single generative AI query requires nearly ten times the power of a standard web search [3], and the Information and Communications Technology (ICT) sector's baseline greenhouse gas emissions are projected to reach 1.3 times their 2015 level by 2030 [4]. This duality (AI as both a solution to and a cause of energy demand growth) constitutes what has come to be called the Twin Transition: the inescapable co-occurrence of digitalization and the energy transition.

For developing economies, the trade-offs are particularly acute. Vietnam is pursuing an ambitious digital transformation agenda while its power grid remains heavily coal-dependent and already experiences periodic capacity shortfalls. The country's data center market is projected to expand at a 14.2% Compound Annual Growth Rate (CAGR) through 2030 [5], with domestic forecasts suggesting AI-driven demand could increase national power consumption by 110% under high-adoption trajectories [6]. Simultaneously, Vietnam's energy-intensive manufacturing base stands to benefit from AI-enabled efficiency gains. Whether the productivity dividends of AI deployment can offset the grid strain and capital costs of digital infrastructure build-out is a central determinant of Vietnam's medium-term growth trajectory.

Despite a growing body of CGE work on digitalization in emerging economies [7, 8], no existing study simultaneously models both the productivity-enhancing and energy-demand-generating channels of AI adoption within the same general equilibrium framework. Zhang et al. [4] demonstrate the importance of this combined approach

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for Japan; their high-income, stable-grid context, however, cannot be directly transferred to Vietnam. This paper fills that gap by simulating three scenarios through 2035 in a 23-sector recursive dynamic CGE model. Section 2 describes the model and scenarios. Section 3 presents the results. Section 4 concludes.

2 Method and Data

2.1 Model Specification

We employ a single-country, recursive dynamic CGE model calibrated to Vietnam's 2019 Input-Output (IO) Table, following Thurlow [9] and Lofgren et al. [10]. The recursive dynamic structure follows the integrated energy and environmental CGE tradition of Liang et al. [11]. The model solves a sequence of static equilibria linked by intertemporal laws of motion for capital, labor, and productivity.

Sectors are indexed by j and commodities by i, with t the time index. Quantity variables, all non-negative, comprise factor inputs L_j, K_j, the value-added composite V_j, gross output X_j, imports M_i, exports E_i, domestic absorption D_i, the Armington composite Q_i, final demands C_i, I_i, G_i, and household income Y_h. Prices are the wage w, sector rental r_j, domestic price P_i and world price p_i^w. CES, CET, Armington and Cobb-Douglas distribution shares $\theta_L, \gamma_i, \delta_i, \beta_i$ all lie in $[0, 1]$ (with $\sum_i \beta_i = 1$); scale parameters α_j, T_i, B_i are strictly positive. The substitution elasticities are $\sigma_{VA} = 0.8$ (calibrated) and $\sigma_{CET}, \sigma_A \in [1.5, 3.0]$, with the curvature parameters $\rho_{VA}, \kappa, \rho_A$ defined accordingly. Capital depreciates at $\delta = 0.05$ per period.

Production. Each sector j produces gross output X_j via Leontief top-level technology combining value-added V_j and intermediate inputs INT_{ij}:

$$X_j = \min\left(\frac{V_j}{a_j^V}, \frac{INT_{ij}}{a_{ij}^Q}\right) \tag{1}$$

The value-added composite is a Constant Elasticity of Substitution (CES) aggregation of labor and capital [12]:

$$V_j = \alpha_j\left[\theta_L L_j^{-\rho_{VA}} + (1-\theta_L)K_j^{-\rho_{VA}}\right]^{-1/\rho_{VA}} \tag{2}$$

Equation 1 forbids substitution between value-added and intermediates at the recipe level. Equation 2 allows imperfect substitution between L and K, with θ_L pinning factor income shares at base prices and σ_{VA} governing factor demand response.

Producer optimisation. Each sector minimises factor cost subject to Equation 2, yielding the conditional factor demand ratio:

$$\frac{L_j}{K_j} = \left(\frac{\theta_L}{1-\theta_L}\right)^{\sigma_{VA}}\left(\frac{r_j}{w}\right)^{\sigma_{VA}} \tag{3}$$

Trade. Output is allocated between domestic sales D_i and exports E_i via a Constant Elasticity of Transformation (CET) function [13]; imports M_i and domestic goods form the Armington composite Q_i [14]:

$$X_i = T_i\left[\gamma_i E_i^{\kappa} + (1-\gamma_i)D_i^{\kappa}\right]^{1/\kappa} \tag{4}$$

$$Q_i = B_i\left[\delta_i M_i^{-\rho_A} + (1-\delta_i)D_i^{-\rho_A}\right]^{-1/\rho_A} \tag{5}$$

Household. The representative household maximises Cobb-Douglas utility $\sum_i \beta_i \ln C_i$ subject to $\sum_i P_i C_i = (1-s)Y_h$, where $Y_h = wL + \sum_j r_j K_j + \mathrm{TR}$ and s is the saving rate clearing the investment-saving balance, yielding $C_i = \beta_i(1-s)Y_h/P_i$, $\sum_i \beta_i = 1$.

Market clearing. Commodity, labor, sector capital, and foreign-exchange markets clear via

$$\textstyle\sum_j INT_{ij} + C_i + I_i + G_i + E_i = X_i + M_i, \tag{6}$$

$\sum_j L_j = \bar{L}(t)$, $K_j = \bar{K}_j(t)$, and $\sum_i p_i^w(M_i - E_i) = \overline{\mathrm{CAB}}$. The CPI is numeraire. After Walras' law, the equation count matches the endogenous variable count and a unique equilibrium is determined for each period.

Capital accumulation. Between periods, capital accumulates via the perpetual inventory method:

$$K_j(t+1) = (1-\delta)\,K_j(t) + I_j(t) \tag{7}$$

Total real investment scales with Gross Domestic Product (GDP) and is distributed proportionally to sectoral rental rates [15]. Labor supply grows exogenously from General Statistics Office of Vietnam (GSO) demographics. Baseline TFP is calibrated each period to reproduce the GSO and Ministry of Planning and Investment medium-term growth path: 6.0% per year on average over 2025-2030, tapering to 5.4% per year over 2030-2035 as the capital-output ratio rises.

2.2 Data and Calibration

The 2019 Vietnam IO table at 171-sector resolution is aggregated to 23 sectors via the concordance reported in the appendix. Share parameters (α_j, θ_L, Armington and CET shares) are recovered by inverting the share equations at the base-year equilibrium, and the calibrated Social Accounting Matrix (SAM) reproduces the 2019 macro aggregates within rounding error. Table 1 summarises the benchmark structure for the 13 largest sectors plus an aggregate "Other" row covering the remaining 10. Elasticities are $\sigma_{VA} = 0.8$ [7, 10], Armington and CET 1.5–3.0 [9, 13], and $\delta = 0.05$ [11].

2.3 Sector Aggregation

The raw 171-sector IO table is aggregated into a 23-sector framework. For the Green AI vector, we disaggregate Heavy Manufacturing and Electricity, the largest industrial emitters and energy consumers. For the Brown AI vector, we isolate IT Hardware and IT Services to track data center and networking infrastructure demands. Remaining sectors are aggregated into standard macroeconomic clusters.

Energy variable. The Electricity sector serves as the model's energy variable, calibrated from the GSO 2019 IO table (generation, transmission and distribution rows) and denominated in 2019 Vietnamese Dong (VND) billion at producer prices. Four quantities are tracked each period: real output $X_{\mathrm{ELEC},t}$, producer price $P_{\mathrm{ELEC},t}$, intermediate demand $\mathrm{INT}_{\mathrm{ELEC},j,t}$ by every using sector (separated from final household consumption), and net trade. Electricity supply-demand balance is the commodity-clearing condition (Equation 6) specialised to $i = \mathrm{ELEC}$. Persistent reallocation of supply from exports to intermediate IT demand under S3, in the absence of output expansion, is the model's signal of binding generation capacity.

2.4 Scenarios

S1 (Business-as-Usual, BAU). The counterfactual. Economy-wide TFP is calibrated to reproduce the official GSO growth path in the absence of AI policy shocks.

S2 (Green AI, Energy Efficiency). AI-driven process optimization in heavy industry and power grids. Within the WEF Global Lighthouse Network, top facilities have demonstrated average energy consumption reductions of 22% [1, 2]. Industry 4.0 adoption is typically modelled in CGE via sector-specific TFP shocks [4, 7]. S2 implements Hicks-neutral productivity shocks to Heavy Manufacturing and Electricity starting in 2025, a cumulative 25% improvement over the decade (annualised 2.26%).

S3 (Brown AI, Digital Infrastructure Demand). A generative AI query consumes nearly ten times the electricity of a standard search [3], and Vietnam's data center market is projected to grow at a 14.2% CAGR through 2030 [5], potentially driving a 110% surge in power demand [6]. Following Okorie et al. [8], S3 implements a multiplicative investment demand shock to IT Hardware and IT Services (a compounded 14.87% annual expansion), forcing IT capacity build-out and proportionally surging intermediate electricity demand.

S4 (Twin Transition). S4 merges the shocks of S2 and S3, reflecting the macroeconomic tension of AI deployment. Zhang et al. [4] demonstrate that only by jointly accounting for ICT-induced electricity demand and ICT-enabled productivity improvements can the net societal benefit of digital expansion be correctly estimated.

Table 1. Sectoral structure of the benchmark economy, 2019.

Sector	%GDP	L VA	K VA	INT	Exp	ImpPen
TradeTransport	15.7	70.6	27.2	42.0	22.3	2.8
PublicServices	12.5	68.3	30.2	39.2	4.4	3.7
FinancialProf	11.1	33.9	64.2	30.2	4.8	5.6
Agriculture	9.8	93.0	6.5	50.9	9.7	20.0
Construction	6.4	81.9	17.5	71.7	0.3	0.3
FoodBeverage	4.5	60.4	38.7	83.5	26.3	15.7
Textiles	4.4	62.8	36.6	73.1	72.3	54.2
HeavyMfg	4.2	62.4	36.3	80.6	19.5	31.7
ITServices	3.7	46.9	52.3	47.4	7.3	9.1
ITHardware	3.6	69.7	29.6	89.6	87.3	83.9
Electricity	3.2	21.7	75.9	43.8	1.0	1.0
Hospitality	3.1	85.9	11.7	59.4	22.6	6.9
LeatherFootwear	1.7	78.2	19.7	71.4	96.8	85.3
Other (10)	16.1	63.1	35.4	65.8	24.9	36.5

3 Results

We present deviations from the S1 BAU baseline for S2 (Green AI), S3 (Brown AI), and S4 (Twin Transition). All figures are percentage differences from the BAU trajectory unless otherwise noted.

3.1 Macroeconomic Overview

Table 2 presents headline deviations at three checkpoints. Figure 1 traces the full GDP deviation trajectory.

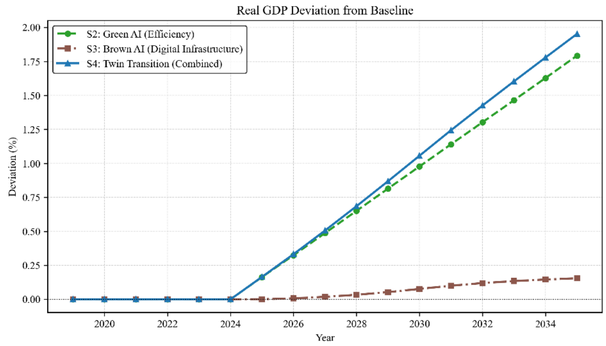

Figure 1. Real GDP deviation from BAU trajectory (%), 2019-2035, by scenario.

S2 delivers a monotonically rising GDP dividend (+0.16% in 2025, +0.98% by 2030, +1.79% by 2035; Figure 1). The compounding TFP shock reduces unit costs in Heavy Manufacturing and Electricity each period, lifting output, profitability, and investment, which feed higher capital stocks in subsequent periods. The growth gap holds steady at +0.17 pp per annum, confirming the productivity impulse is trend-shifting rather than cyclical, consistent with Zhang et al. [4].

S3 is effectively macro-neutral (+0.08% GDP by 2030, +0.16% by 2035). The exogenous capital injection expands IT capacity but does not raise economy-wide TFP; investment resources are diverted from consumption, leaving aggregate GDP approximately unchanged. S4 is approximately the linear sum of S2 and S3 (+1.06% by 2030, +1.95% by 2035), with limited negative interaction. The exchange rate summarises this: S2 appreciates by −0.57% at 2030 (export-driven), S3 is near-neutral (+0.07%), and S4 mirrors S2 at −0.50%.

3.2 Capital, Investment, and Welfare

Capital and welfare reveal a fundamental asymmetry between the two AI vectors (Figure 2). Under S2, capital grows to +0.21% by 2030 and +0.73% by 2035: higher TFP raises rental rates, drawing investment toward Heavy Manufacturing and Electricity [15]. This feeds household welfare cleanly: real consumption rises +0.27%, +1.17%, +2.03% in 2025, 2030, 2035, supported by real wage gains of +0.19%, +0.84%, +1.35%.

S3 presents the opposite pattern: capital deepening without welfare gains. Investment is +1.13% at 2030

Table 2. Macroeconomic deviations from BAU baseline (% unless noted)

Scenario	Year	Real GDP (%)	Growth gap (pp)	Capital stock (%)	Investment (%)	Real wage (%)	Real ER (%)
S2 Green AI	2025	+0.16	+0.17	0.00	0.00	+0.19	−0.11
	2030	+0.98	+0.17	+0.21	+0.81	+0.84	−0.57
	2035	+1.79	+0.17	+0.73	+1.63	+1.35	−0.93
S3 Brown AI	2025	0.00	0.00	0.00	+0.12	0.00	+0.02
	2030	+0.08	+0.02	+0.29	+1.13	+0.12	+0.07
	2035	+0.16	+0.01	+0.77	+1.22	+0.24	0.00
S4 Twin	2025	+0.17	+0.18	0.00	+0.12	+0.19	−0.09
	2030	+1.06	+0.20	+0.49	+1.95	+0.95	−0.50
	2035	+1.95	+0.18	+1.51	+2.87	+1.58	−0.92

Note: A negative ER deviation denotes real appreciation. Baseline GDP growth: 6.0%/yr (2025-2030), 5.4%/yr (2030-2035).

while real consumption falls to −0.42% as forced investment must be financed by reduced household spending. Wages rise only +0.12%, confirming that capital owners, not workers, are the primary near-term beneficiaries of the Brown AI build-out.

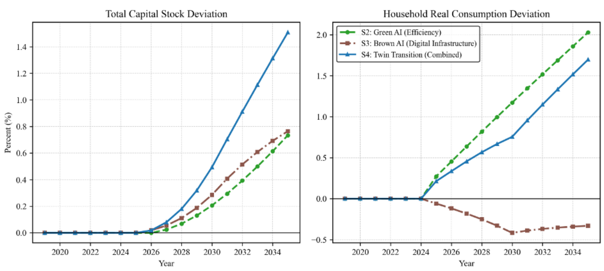

Figure 2. Capital stock and real household consumption deviation from BAU (%), 2019-2035, by scenario.

S4 resolves the tension in favor of net welfare gains. Capital accumulates super-additively to +1.51% above BAU by 2035, exceeding the sum of S2 (+0.73%) and S3 (+0.77%). Consumption is +0.21%, +0.75%, +1.70%: Green AI's wage and income effects dominate, more than compensating for the forced saving imposed by Brown AI.

3.3 Energy Sector Outlook

Table 3 reports the projected Electricity-sector paths under each scenario.

Under S3 (Brown AI), real electricity output rises only +0.10% by 2030 even though intermediate demand from IT Hardware and IT Services expands at 14.87% per year. The grid does not augment supply within the horizon: the gap is closed by reallocating the small export margin (+0.51% above baseline) and by the producer price barely moving (−0.14%), both consistent with binding generation capacity. S2 and S4 relax this constraint via the productivity shock: output expands by 5.6 to 5.7% at 2030 and above 10% at 2035, with prices falling 8.4 to 11.5%. The policy implication is direct: the Brown AI build-out is energy-feasible only when paired with productivity gains in generation; absent S2, the Twin Transition encounters a quantitative power-supply shortfall before 2030.

Table 3. Electricity sector outlook through 2035.

Scenario	Year	Output	Price	Exports
S1 (level)	2025	610	1.00	9
	2030	847	0.67	17
	2035	1,141	0.59	28
S2 (%dev)	2025	+1.22	−3.23	+7.7
	2030	+5.60	−8.43	+23.8
	2035	+10.58	−11.26	+36.4
S3 (%dev)	2025	0.00	+0.00	+0.02
	2030	+0.10	−0.14	+0.51
	2035	+0.23	−0.34	+0.88
S4 (%dev)	2025	+1.22	−3.23	+7.7
	2030	+5.70	−8.53	+24.4
	2035	+10.85	−11.51	+37.5

3.4 External Sector Adjustment

Under S2, the real exchange rate appreciates consistently (−0.11%, −0.57%, −0.93% in 2025, 2030, 2035; Figure 3). Lower industrial costs make Vietnam's heavy manufactures globally competitive: Heavy Manufacturing exports surge +21.4% and Electricity exports +23.8% at 2030, generating excess demand for VND. The appreciation redistributes the productivity dividend to domestic purchasers while eroding margins for other exporters.

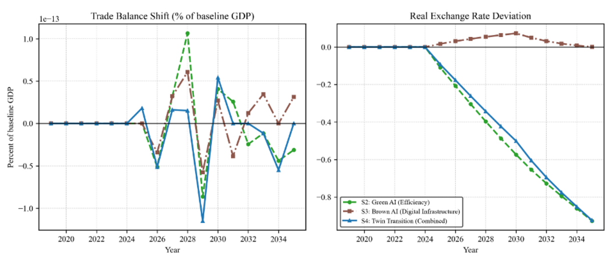

Figure 3. Real exchange rate deviation from BAU (%) and sectoral export paths, 2019-2035.

S3 produces near-neutral exchange rate movement (+0.07% at 2030): the IT investment shock is domestically absorbed. S4 inherits S2's appreciation at −0.50% by 2030, confirming that the combined scenario's external position is driven by productivity, not capital dynamics.

3.5 Sectoral Reallocation

In S2, TFP shocks propagate via two channels. The shocked sectors expand: Heavy Manufacturing +12.44% at 2030 with prices −5.46%, Electricity +5.60% with prices −8.43%. Cheaper electricity then reduces intermediate costs economy-wide: Machinery (+6.24%), IT Hardware (+9.78%), Construction (+0.85%) all gain (Figure 4).

The second channel is the real exchange rate. The export surge appreciates VND, eroding the competitiveness of price-sensitive export sectors. Textiles contracts −6.16% and Leather and Footwear −16.88% at 2030, with export losses of −6.36% and −17.26%. This is a sector-specific Dutch Disease: the productivity boom in heavy industry strengthens VND and squeezes garment and footwear exporters.

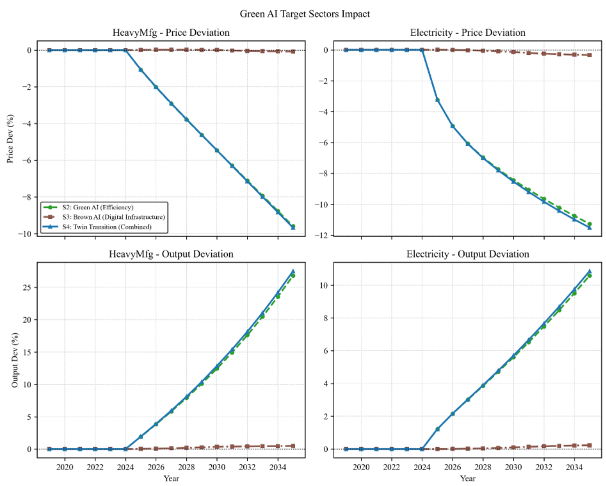

Figure 4. Deviations from BAU, key Green AI sectors (%), 2019-2035.

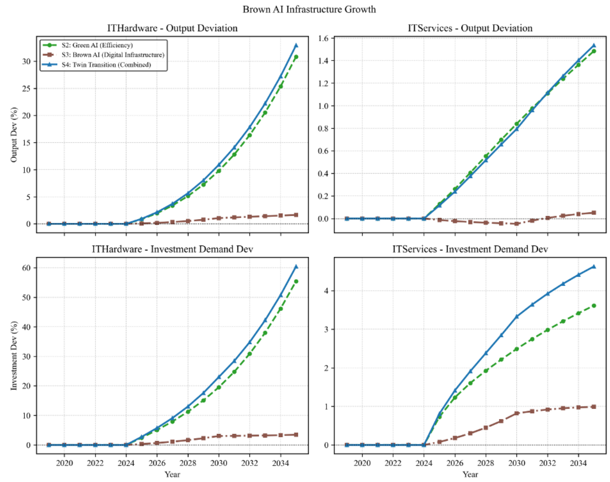

Figure 5. Deviations from BAU, key Brown AI sectors (%), 2019-2035.

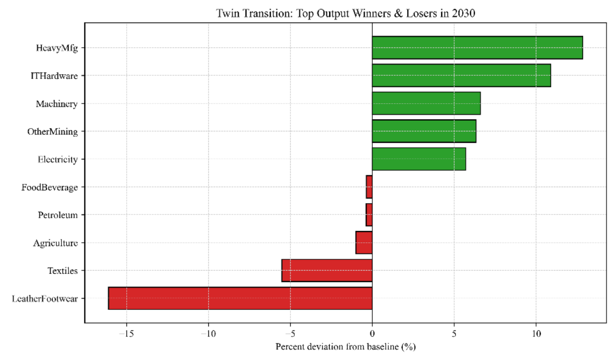

Figure 6. Sectoral gross output deviation from BAU (%) under S4 Twin Transition at 2030.

In S3, sectoral effects are an order of magnitude smaller. IT Hardware gains most (+1.06%), while Textiles and Leather and Footwear record small positive deviations from general investment demand (Figure 5).

In S4, winners gain more than under S2 alone: Heavy Manufacturing +12.85%, IT Hardware +10.90%, Machinery +6.60%, Electricity +5.70% (Figure 6). The super-additive gains reflect a general equilibrium complementarity: Brown AI's IT capacity expansion generates additional intermediate demand for the heavy manufactured inputs that Green AI has made cheaper. Losers (Leather and Footwear −16.10%, Textiles −5.51%, Agriculture −1.00%) are slightly less exposed than under S2 alone.

4 Conclusion

This paper examined the macroeconomic and structural consequences of Vietnam's Twin Transition using a recursive dynamic CGE model through 2035. The two AI vectors operate through fundamentally different channels. Green AI (S2) generates a compounding productivity dividend (GDP +1.79% above BAU by 2035, consumption +2.03%) through lower industrial input costs, rising wages, and export-driven exchange rate adjustment. Brown AI (S3) is macro-neutral in GDP but imposes a near-term consumption sacrifice of −0.42% by 2030 as forced infrastructure investment crowds out household expenditure. The Twin Transition (S4) is approximately additive (GDP +1.95%, consumption +1.70% by 2035), confirming that the efficiency dividend of Green AI more than offsets the welfare drag of the infrastructure build-out.

The energy outlook in Section 3.3 adds a critical caveat: under Brown AI alone, electricity output rises only +0.10% by 2030 against a 14.87%/yr IT investment surge, indicating binding generation capacity. The Green AI productivity shock is therefore necessary, not merely beneficial, to make the Twin Transition energy-feasible. The most consequential finding is distributional. Real exchange rate appreciation displaces labor-intensive exporters (Textiles −5.5 to −6.2%, Leather and Footwear −16.1 to −16.9%) regardless of scenario. This appreciation mechanism, analogous to a sector-specific Dutch Disease, is an inherent feature of productivity-driven competitiveness gains in a small open economy. Vietnam's Twin Transition is therefore macro-feasible and welfare-improving in aggregate, but the adjustment costs fall unevenly on traditional export industries that employ a large share of the manufacturing workforce. Complementary labor market policies, skills retraining, and targeted industrial support for displaced sectors are essential to ensure that the aggregate gains are broadly shared.

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